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METHOD AND APPARATUS FOR FORMING FIBRE REINFORCED METAL MATERIAL USING MOLTEN METAL UNDER PRESSURE

Abstract:

Abstract of GB2255351

The invention provides for the production of fibre reinforced metal materials by feeding the fibres (5) through an entry port (6) in a receptacle (4) and into molten metal (8) which is contained under pressure in the receptacle (4) as illustrated in Fig. 1. The temperature and pressure of the molten metal (8) are controlled so that the composite material (11) can be withdrawn via an exit port (12) of the receptacle (4). Pressure is maintained by supplying a gas, such as nitrogen, through the orifice (13) at a pressure of 14-105.5 kgcm<-2> which will overcome surface tension for metal infiltration. The temperature is maintained at the correct temperature for coating, ideally 650 - 750 DEG C, by electric heaters (7). Preferably means are provided for controlling at least one of the rate of feed of the fibres and the temperature and pressure of the molten metal to effect solidification of the molten metal in the exit port. The entry port may be caused to reciprocate relative to the fibres passing therethrough. The fibres used are generally ceramic, eg alumina, silicon carbide or carbon but may also be metal, eg steel wire. The fibres may be used in the form of individual filaments, bundles or tows, or in woven form.

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(56) Documents cited
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GB 1188721 A GB 1116221 A GB 0986664 A
EP 0177345 A1 EP 0165683 A1 EP 0134143 A1
US 4644898 A US 4478892 A US 4444814 A
US 4418100 A

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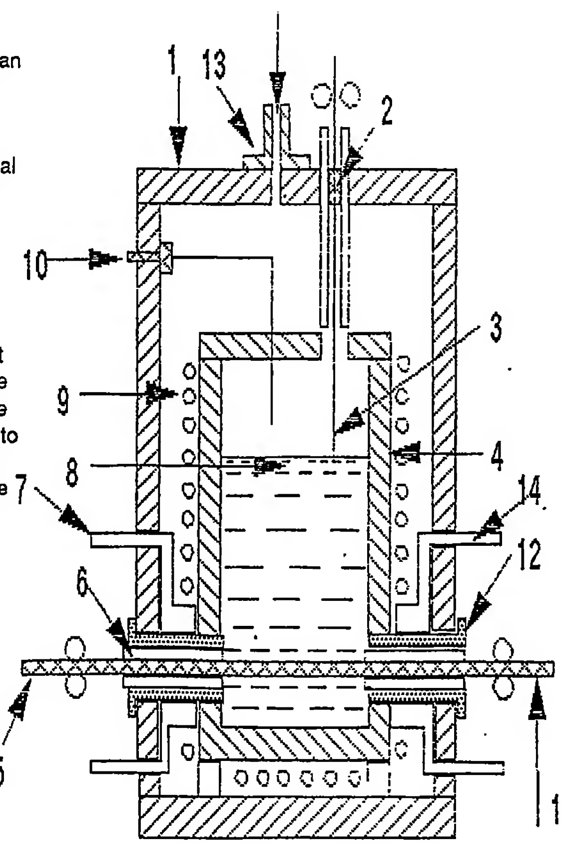
INT CL[5] B05C, C23C
Online databases: WPI, CLAIMS

(54) Method and apparatus for forming fibre reinforced metal material using molten metal under pressure

(57) The invention provides for the production of fibre reinforced metal materials by feeding the fibres (5) through an entry port (6) in a receptacle (4) and into molten metal (8) which is contained under pressure in the receptacle (4) as illustrated in Fig. 1. The temperature and pressure of the molten metal (8) are controlled so that the composite material (11) can be withdrawn via an exit port (12) of the receptacle (4). Pressure is maintained by supplying a gas, such as nitrogen, through the orifice (13) at a pressure of 14–105.5 kgcm^{-2} which will overcome surface tension for metal infiltration. The temperature is maintained at the correct temperature for coating, ideally 650 – 750°C, by electric heaters (7). Preferably means are provided for controlling at least one of the rate of feed of the fibres and the temperature and pressure of the molten metal to effect solidification of the molten metal in the exit port. The entry port may be caused to reciprocate relative to the fibres passing therethrough. The fibres used are generally ceramic, eg alumina, silicon carbide or carbon but may also be metal, eg steel wire. The fibres may be used in the form of individual filaments, bundles or tows, or in woven form.

FIGURE 1



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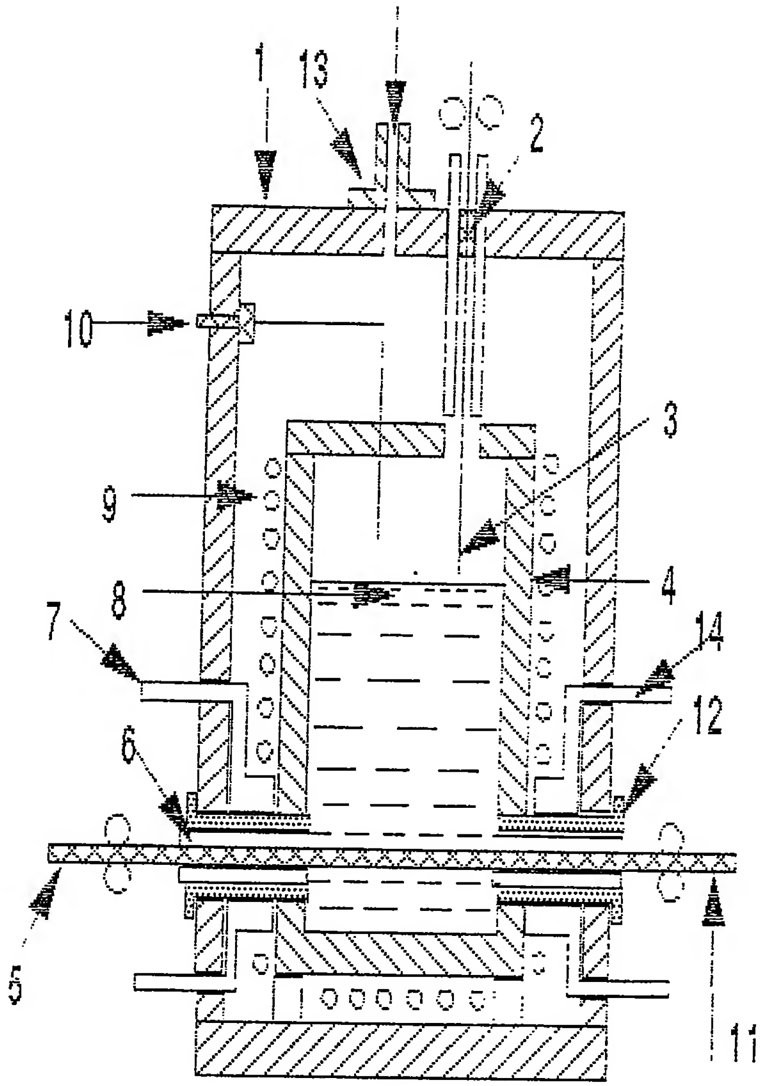

FIGURE 1

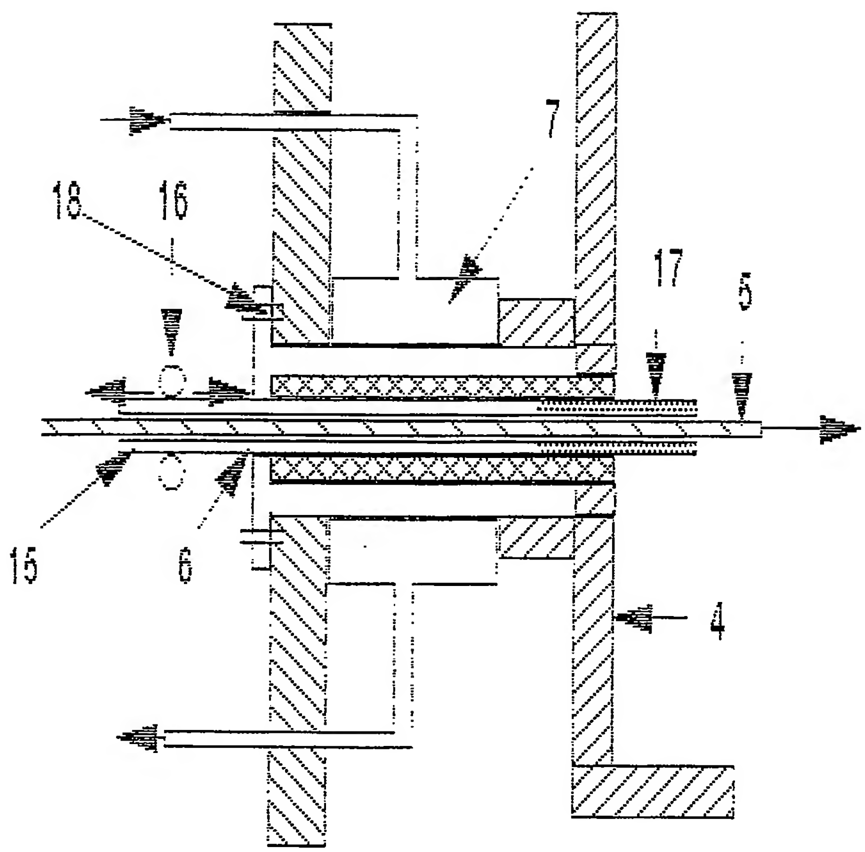

FIGURE 2

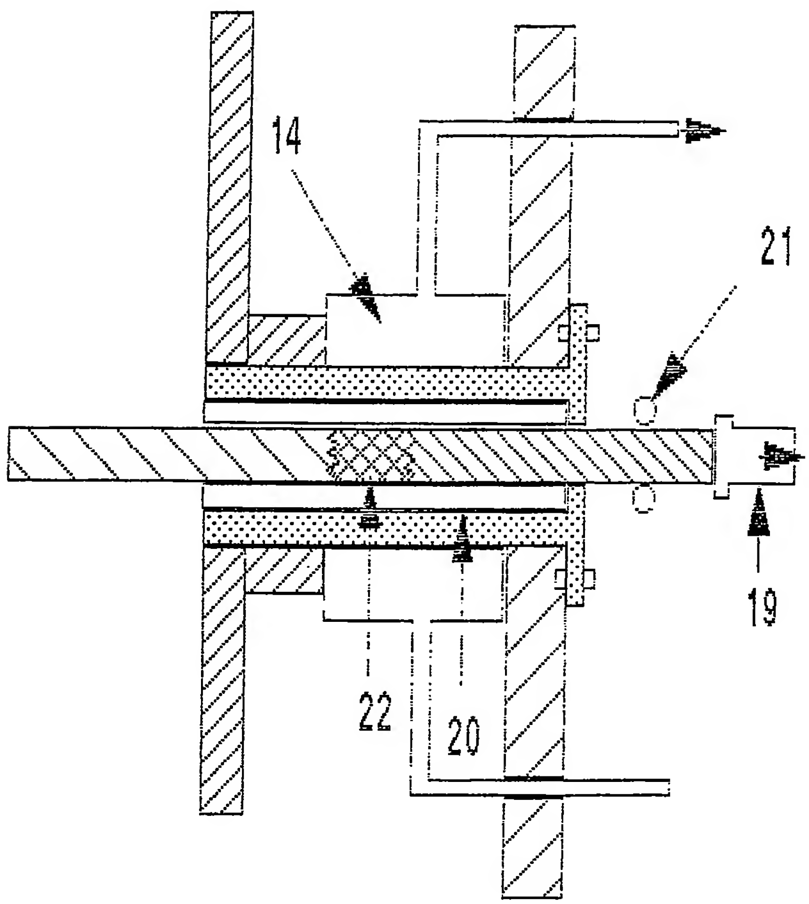

FIGURE 3

METHOD AND APPARATUS FOR FORMING FIBRE REINFORCED METAL MATERIAL

The present invention relates to the production of fibre reinforced metal material. In particular, it relates to a process and apparatus for the continuous production of fibre reinforced metals.

Production of fibres and their pretreatment in readiness for use in the reinforcement of metal is disclosed in various patent specifications, including US-A-3754112, US-A-4045597, US-A-4068037, US-A-4123583, US-A-4127659, US-A-4142008, US-A-4315968, US-A-4340636, US-A-4415609 and US-A-4481257.

In GB-A-2168032 there is described a process for making reinforced rings by stacking modules in a die which are formed by co-winding of a filamentary reinforcement and of a metal strip, with interspersed foils of a matrix metal such as aluminium, titanium, copper or magnesium. The assembly is then consolidated by the application of heat and pressure.

In US-A-3913657 A process and apparatus are described where metal in a lower chamber is melted and pressurised. A second, evacuated, higher chamber containing fibres is lowered onto the lower chamber which is thereby pierced and so causes metal to infiltrate the fibres due to the pressure differential.

Gas pressure is used to encourage infiltration in US-A-3547180, where a billet of metal is melted over a fibre preform.

Published document JP-A-60/29433 describes a batch process and associated apparatus in which a fibre preform is placed in a metal die, molten metal poured onto the fibres,

and then subjected to pressure by means of a plunger.

The resulting composite is withdrawn, whilst further fibres are fed into the die through an orifice in the plunger. The metal feed can only be effected by first withdrawing the plunger. The length of composite that can be produced is therefore limited to the volume of metal used on each occasion.

In JP-A-57/70064 apparatus is described where molten metal is delivered by low gas pressure from a holding furnace to a nozzle adjacent to a pair of pinch rollers.

According to one aspect of the present invention there is provided a method of forming fibre reinforced metal material comprising the steps of providing molten metal under pressure in a receptacle having a fibre entry port and a fibre exit port, feeding the fibres through the entry port to contact the molten metal and controlling the temperature and the pressure of the molten metal in the receptacle so that the fibre reinforced metal material can be extracted from the receptacle through the exit port.

Preferably, solidification of the molten metal in the exit port is effected by adjustment of at least one of the rate of feed of the fibres and the temperature and the pressure of the molten metal.

Further, at least one of the parts is cooled by cooling means which may comprise a water cooling system.

According to another aspect of the invention, there is provided apparatus for the production of fibre reinforced metal material comprising a receptacle for receiving molten metal which the fibre is to reinforce, the receptacle having an entry port and an exit port, means for maintaining the molten metal at a predetermined temperature or within a predetermined temperature range, means for maintaining the molten metal at a predetermined pressure or within a predetermined pressure range, means for feeding the fibre

through the entry port and through the molten metal and for feeding the fibre reinforced metal material outwardly of the exit port.

Preferably, the apparatus has means for controlling at least one of the rate of feed of the fibres and the temperature and the pressure of the molten metal to effect solidification of the molten metal in the exit port, which may also include a stepper motor for controlling the rate of feed of the fibre.

Further, the entry port may comprise a reciprocable sleeve, which may be arranged such that the stroke of movement of the sleeve in the direction of travel of the fibres is synchronised with each stepped movement of the fibres.

The fibres may be used in the form of individual filaments, in the form of bundles or tows, or in woven form, or in any other form suitable for the reinforcement of metals. The fibres may be coated to assist in the prevention of damage by the molten metal. The fibre diameter may be in the range 3μm to 250μm or more.

The fibres used are generally ceramic, for example; alumina, silicon carbide, carbon, etc. but may also be metal e.g. steel wire. However, any fibres that can be constituted into appropriate preforms can be used. Coatings that assist wetting are not necessary, since the applied pressure is sufficient to overcome surface tension forces. Should fibres that are susceptible to chemical damage be used then a resistant coating (e.g. silicon carbide, carbon etc.) is beneficial. The metal to be used may be any metal suitable for the formation of a matrix material. Typical examples include: aluminium, copper, zinc, lead, magnesium and their alloys.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings

in which:

Fig. 1 is a cross-sectional view through apparatus embodying the invention;

Fig. 2 is a cross-sectional view of the entry port of the apparatus of Fig. 1; and

Fig. 3 is a cross-sectional view of the exit port of the apparatus of Fig. 1.

Fig. 1 shows the pressure vessel 1 containing a crucible 4 which holds the charge of molten metal 8. This vessel is heated to ensure the metal is maintained at the correct temperature (typically between 650°C and 750°C) by the electric heaters 9. The metal level is maintained at a constant level by a constant or periodic feed of metal wire 3, of the same composition as the existing melt, through a gas pressure seal 2.

Ceramic fibres 5 are fed into the melt crucible by the mechanism 6 outlined in Fig. 2. Escape of the molten metal 8 is prevented by the use of a cooling jacket 7 around the entry mechanism 6 to reduce the temperature well below the solidification temperature of the particular metal.

The fibres are infiltrated under pressure as they pass through the melt. They then pass into the exit mechanism 12 (shown further in Fig 3) where the fibres are collimated and metal solidification occurs due to the lower temperature of this mechanism, which is cooled by a second cooling jacket 14.

After solidification the material exits as consolidated metal composite.

The production is continuous as long as fibres are fed in and the metal wire supply is continued.

Pressure is maintained by the supply of gas through the orifice 13. The gas should preferably be inert, e.g. nitrogen and the pressure in the range 200psi ($14kgcm^{-2}$) to 1500psi ($105.5kgcm^{-2}$).

A probe 10 is employed to monitor the melt level so as to ensure that the metal does not exceed a desired level.

The form of the composite material withdrawn from the receptacle follows the shape of the internal form of the exit die.

Fig. 2 shows the arrangement for controlled ingress of fibres into the pressure vessel and to the melt crucible.

The fibres 5 enter a collimator tube 15 which is moved in a reciprocating motion by a pair of pinch rollers 16. The reciprocating motion is synchronised with the pinch rollers 21 (Fig. 3) which are driven by a stepper motor such that during each period of stepped motion of the fibre material, the collimator tube 15 moves in the same direction as the fibre material. Such reciprocating motion advantageously assists in preventing damage or breakage of the fibres. The portion 17 of the collimator exposed to the molten metal is formed of a ceramic material. Such material can be any ceramic which will not suffer damage from molten metal, typically silicon nitride or silicon carbide. The cooling jacket 7 ensures that the temperature gradient through the collimator is such that pressurised metal in the holding crucible 4 solidifies before escaping. Such a measure creates a gas tight seal. The gas in the pressure vessel is prevented from escaping by a Flexitallic seal 18 (trade name) at the junction of the collimator flange and the pressure vessel,

Fig. 3 shows the assembly for the controlled exit of the composite material.

A mechanically constrained hydraulic ram 19 is positioned at a preset distance from the exit die 20. A starter rod of the chosen metal - having a required cross section-is held in position by a set of pinch rollers 21 and is restrained by a force exerted by the ram equivalent to the applied gas pressure in the pressure vessel as a

function of the cross sectional area. The hydraulic ram is then retracted. A stepper motor (not shown) drives the pinch rollers 21 so as to control the fibre-material extraction rate

The extraction rate is controlled such that solidification of the melt introduced to the fibres is complete prior to exit from the collimator. The particular location of the solidification region 22 in the collimator is controlled by the cooling jacket 14.

The rate of extraction of composite material is a function of the degree of cooling supplied by the cooling jacket 14, the type of fibres used, the degree of superheat of the chosen metal, and the rate of extraction.

Thermocouples (not shown) are used to monitor and control the position of the solidification region and thereby the extraction rate.

The process and apparatus illustrated are suitable for the continuous casting of sheet, strip, bar, tube or shaped section.

It will be appreciated by those skilled in the art that the production of sound material will be a function of the following factors:

1. Entry and exit die temperatures;
2. Infiltration pressure;
3. Heat extraction capacity of the exit die;
4. Molten metal temperature;
5. Fibre feed rate;
6. Fibre type/coating.

Careful control of the entry die temperature is necessary to prevent metal escape. This also applies to the exit die, but, in addition, the temperature must be such that molten metal solidification occurs in the correct region of the die (Fig. 3).

The infiltration pressure must be sufficient to ensure

complete infiltration of the fibres. This will be a function of the degree of fibre packing, or ultimately the fibre volume fraction. Small diameter fibres tightly packed will therefore require a higher infiltration pressure.

The extraction of heat from the exit die must be controlled to ensure solidification occurs in the correct region of the die. Too low an extraction rate will allow solidification to occur in a region that is not substantially under gas pressure.

The metal temperature must be controlled so that it is not so high as to encourage gas absorption and fibre damage, but not so low that the surface tension requires excessively high infiltration pressures. The fibre feed rate should be sufficiently high to reduce to a minimum fibre attack, but not so high as to result in incomplete solidification, and metal escape.

The feed rate will also be influenced by the fibre type and the presence or absence of a fibre coating.

Fibre coatings are generally beneficial since they reduce metal attack and can aid infiltration.

CLAIMS

1. A method of forming fibre reinforced metal material comprising the steps of providing molten metal under pressure in a receptacle having a fibre entry port and a fibre exit port, feeding the fibres through the entry port to contact the molten metal and controlling the temperature and the pressure of the molten metal in the receptacle so that the fibre reinforced metal material can be extracted from the receptacle through the exit port.

2. A method as claimed in claim 1, wherein solidification of the molten metal in the exit port is effected by adjustment of at least one of the rate of feed of the fibres and the temperature and the pressure of the molten metal.

3. A method as claimed in claim 1 or 2, wherein at least one of the ports is cooled by cooling means.

4. A method as claimed in claim 3, wherein the cooling means comprises a water-cooling system.

5. A method as claimed in any preceding claim, wherein the location of the solidification of the molten metal is monitored.

6. A method as claimed in claim 5, wherein the location is monitored by thermocouple means.

7. A method as claimed in claim 5 or 6, wherein the operating conditions in the receptacle are adjusted in response to an output obtained from the monitoring.

8. A method as claimed in any preceding claim, wherein the molten metal is pressurised by means of a controlled gas pressure in the receptacle.

9. A method as claimed in any preceding claim, wherein the fibres are introduced in the form of individual

filaments, tows or bundles, or in woven form.

10. A method as claimed in any preceding claim, wherein the molten metal in the receptacle is replenished by means of the introduction of solid metal thereto.

11. A method as claimed in claim 10, wherein the solid metal is in form of a metal rod.

12. A method as claimed in any preceding claim, wherein the fibres have a diameter in the range of approximately 3μm to approximately 250μm.

13. A method as claimed in any preceding claim, wherein the fibres comprise steel or other metal wire, alumina fibres, carbon fibres or silicon carbide fibres.

14. A method as claimed in any preceding claim, wherein the metal comprises titanium, copper, aluminium, magnesium, lead, zinc or an alloy of any two or more thereof.

15. A method as claimed in any preceding claim, in which the controlled gas pressure required to overcome surface tension for metal infiltration is in the range 150psi (10.55 $kgcm^{-2}$) to 1500psi (105.5 $kgcm^{-2}$).

16. A method as claimed in any preceding claim, wherein at least the entry port is caused to reciprocate relative to the fibres passing therethrough.

17. A method as claimed in any preceding claim, wherein the fibres are extruded through a die at the entry port and/or at the exit port.

18. Apparatus for the production of fibre reinforced metal material comprising a receptacle for receiving molten metal which the fibre is to reinforce, the receptacle having an entry port and an exit port, means for maintaining the molten metal at a predetermined temperature or within a predetermined temperature range, means for maintaining the molten metal at a predetermined pressure or within a predetermined pressure range, means for feeding the fibre

through the entry port and through the molten metal and for feeding the fibre reinforced metal material outwardly of the exit port.

19. Apparatus as claimed in claim 18, having means for controlling at least one of the rate of feed of the fibres and the temperature and the pressure of the molten metal to effect solidification of the molten metal in the exit port.

20. Apparatus as claimed in claim 19, including a stepper motor for controlling the rate of feed of the fibre.

21. Apparatus as claimed in any of claims 18 to 20, having means for cooling the temperature of the entry and/or exit port.

22. Apparatus as claimed in claim 21, wherein the cooling means comprises a water-cooling system

23. Apparatus as claimed in any of claims 18 to 22, having means for monitoring the location of the solidification of the molten metal in the entry and/or exit port.

24. Apparatus as claimed in claim 23, wherein the monitoring means comprises a thermocouple temperature sensor.

25. Apparatus as claimed in claim 23 or 24, wherein the location of the solidification within the port or ports is controlled in response to an output from the monitoring means.

26. Apparatus as claimed in any of claims 18 to 25, wherein at least the entry port is reciprocable relative to the fibre passing therethrough.

27. Apparatus as claimed in any of claims 18 to 26, wherein the entry and/or exit port comprises a die for the extrusion of material therethrough.

28. Apparatus as claimed in any of claims 18 to 27, wherein said receptacle is housed within a pressure vessel

having an entry and an exit port aligned with said respective ports of the receptacle.

29. Apparatus as claimed in claim 28, wherein the pressure vessel has an inlet port for the introduction of metal material so as to replenish the molten metal in the receptacle.

30. Apparatus as claimed any of in claims 18 to 29, wherein the means for pressurising the molten metal comprises gas supply means.

31. Apparatus as claimed in any one of claims 18 to 30 having heating means for heating and/or maintaining temperature of the molten metal.

32. A method of forming fibre reinforced metal material substantially as hereinbefore described with reference to and as illustrated in Figs. 1, 2 and 3 of the accompanying drawings.

33. Apparatus for the production of fibre reinforced metal material substantially as hereinbefore described with reference to and as illustrated in Figs. 1, 2 and 3 of the accompanying drawings.

12.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

9109327.8

Relevant Technical fields

(i) UK Cl (Edition K) C7F (FGB, FGX, FGZ); B2L (LCFA)

(ii) Int Cl (Edition 5) C23C; B05C

Search Examiner

P G BEDDOE

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI CLAIMS

Date of Search

26 NOVEMBER 1991

Documents considered relevant following a search in respect of claims 1-33

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2179270 A (STC) See especially page 1 lines 83-106	1, 18
X	GB 2063306 A (PHENIX) See especially page 1 lines 54-63	1, 8, 14, 18, 30
X	GB 1444663 A (TELEFONAK...) See especially Claim 1 page 2 lines 33-65	1, 18
X	GB 1188721 A (GEC) See especially page 2 lines 33-65	1, 8, 14, 18, 30
X	GB 1116221 A (NATIONAL STEEL) See especially page 2 lines 27-43; page 4 lines 19-32 and Figure 3	1, 8, 14, 18, 30
X	GB 986664 A (BIRGER) See especially Claim 1, page 2 lines 98-116	1, 18
X	EP 0177345 A1 (CORNING) See page 7 lines 7-26	1, 18
X	EP 0165683 A1 (STC) See especially page 3 line 22 - page 4 line 22	1, 18, 30
X	EP 0134143 A1 (NIPPON) See especially page 9 lines 4-20, example 1	1, 8, 14, 18, 30

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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Patents Act 1977 14
Examiner's report to the Comptroller under Section 17 (The Search Report)

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Relevant Technical fields

(i) UK Cl (Edition) Contd. from page 1

(ii) Int Cl (Edition)

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

Date of Search

Documents considered relevant following a search in respect of claims

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	US 4644898 A (US PHILIPS) See especially column 6 lines 13-57	1, 18
X	US 4478892 A (NATIONAL STEEL) See Figure 1; column 4 lines 21-43	1, 8, 18, 30
X	US 4444814 A (ARMCO) See especially Figure 2	1, 8, 18 30
X	US 4418100 A (REPUBLIC STEEL) See especially Figure 2	1, 8, 18 30

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Category	Identity of document and relevant passages	Relevant to claim(s)

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